Canadian Centre
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MAGNETIC FIELDS IN THE WORKPLACE

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This publication was prepared as a source of information for health and safety committees and others with an interest in understanding and reducing the risk of exposure to magnetic fields in the workplace.

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1. INTRODUCTION

People cannot avoid exposure to magnetic fields--the earth itself has a magnetic field. But recent technological developments have resulted in an increased number of sources of magnetic fields.

This publication briefly summarizes the various sources of magnetic fields, typical exposure levels, and the health hazards from magnetic field exposure. It also provides a summary of existing exposure guidelines and control measures.

2. SOME BASICS OF MAGNETIC FIELDS

A number of sources can produce magnetic fields, including permanent magnets and electric current flowing in a wire. In fact, whenever electric current flows, it produces a magnetic field. Magnetic fields are either static or time-varying.

A *static* magnetic field does not change in strength or direction. Typical examples are the earth's magnetic field and the field from the flow of direct current.

A *time-varying* magnetic field changes in strength or direction at regular intervals. The flow of alternating current typically produces this field. We measure the number of cycles produced per second, or frequency, in hertz (Hz).

Several different units are commonly used to report the strength of a magnetic field. The most common are amperes (A) per meter (A/m), tesla (T) and gauss (G). The gauss and tesla are very large units, so we report field strengths in thousandths of a gauss or milligauss (mG), thousandths of a tesla or millitesla (mT), or even millionths of a tesla or microtesla (uT). The following summarizes the relationship between these units.

- 1 ampere per meter = 12.5 milligauss
  = 1.25 microtesla
  = 0.00125 millitesla
- 1 microtesla = 0.8 amperes per meter
  = 10.0 milligauss
  = 0.001 millitesla
- 1 millitesla = 800 amperes per meter
  = 10,000 milligauss
  = 1,000 microtesla
- 1 milligauss = 0.08 amperes per meter
  = 0.1 microtesla
  = 0.0001 millitesla

3. SOURCES OF MAGNETIC FIELD EXPOSURE

We are all constantly exposed to the earth's steady magnetic field. The earth's field strength ranges from about 70 uT at the poles, to about 30 uT at the equator. Intense solar activity and thunderstorms produce naturally occurring, time-varying magnetic fields. Field levels range from 0.03 uT to 0.5 uT.[1] The flow of electric current produces magnetic fields. As a result, all electrical devices, including appliances, machines and wiring are possible sources of magnetic field exposure.

Many workplaces contain sources of magnetic fields. These sources include high-energy technologies, medical imaging, electricity distribution, video display terminals and industrial heating.

High-Energy Technologies

High-energy technologies, including superconducting generators and parts of thermonuclear fusion reactors, produce high-strength magnetic fields. Some of these devices use superconducting magnets and can generate fields up to 12 T. Worker exposure may reach about 140 mT.[2] In a reactor with an internal static magnetic field of 10 T, worker exposure levels range between 5 and 10 mT under normal conditions.[3]

In research facilities, particle accelerators or bubble chambers are sources of magnetic fields. Workers are exposed to magnetic fields during the changing of film cassettes. Levels range from 0.4 to 0.5 T at foot level to about 0.05 T at head level.[1]

Medical Imaging

Some hospitals use magnetic resonance imaging (MRI) devices for diagnostic purposes. They use them to produce images of all major organ systems and tissues. These devices use static and time-varying magnetic fields. The combination of the fields allows for medical imaging with a high degree of clarity.

Measurements have shown that levels of a static magnetic field near the unit could be above 100 mT, but MRI operators usually spend only about five minutes per patient in this area. Most of the time, operators are close to the operating console where the field strength is below 1 mT.[4]

Electricity Distribution

Magnetic fields are present wherever electric current flows--during the generation, transmission, distribution and end use of electrical energy.

Electric power starts to flow from the generating station. It flows through miles of high voltage power lines, through switchyards and distribution lines, to homes, office buildings and factories. The higher the current, the stronger the field strength. The currents in a powerline depend on power consumption, which can vary greatly depending on the time of day, time of year and weather

conditions. In North America, the magnetic fields that electricity distribution produces are at a frequency of 60 Hz. The field strength weakens with increasing distance from the wires.

Various occupations are routinely exposed to 60 Hz magnetic fields. Workers with a potential for highest exposures include:

- electrical utility workers who maintain the electrical network
- other workers whose occupations require close work to transmission lines such as farmers, and to distribution lines such as telephone utility employees

Appendix A summarizes exposure levels for some electrical utility occupations.

Industrial Heating and Other Uses

Induction Heaters

Some workplaces use induction heaters to process metals. Typical uses include surface or deep hardening, welding, melting, brazing, and annealing metals.

The work piece is placed in an alternating magnetic field produced by coils of various sizes and shapes that are compatible with the work piece. When the electric current flows through the coil, it produces a magnetic field. The magnetic field in turn induces an alternating electric current in the work piece. This alternating current flow heats up the work piece.

Induction heaters operate at high power levels, up to a few hundred kilowatts, and at frequencies ranging from 50 Hz to tens of megahertz (MHz). Usually, workplaces use heaters operating at frequencies below 1000 Hz for melting metals. These are called induction furnaces.

Magnetic field levels at the operator's position may pose a potential health hazard. Typical levels near devices operating between 50 Hz and 10 kilohertz (kHz) range from 1 to 6 mT, and levels from devices operating between 100 kHz and 10 MHz range from 0.7 to 10.7 uT at the operator's position.[5]

Arc Welding

Electric welding units are also sources of magnetic fields. Arc welding uses alternating or direct currents of up to 600 A. Flash welding uses currents of up to 100,000 A or 100 kiloamperes (kA). These welding processes generate magnetic fields ranging from 0.1 mT to 10 mT, depending on the current strength and other factors.[6] Appendix B summarizes magnetic field strengths at the body of an arc welder.

Crack Detection

Magnetic fields are used to detect cracks and fatigue in metal parts. A magnetized test object develops magnetic fields wherever there are cracks or other defects. A magnetic powder applied to the object accumulates at the cracks. When UV light is directed towards the test object, the magnetic powder accumulations appear as a glowing strip on a dark background.

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The current used in the coils to produce the magnetic field can vary in strength up to 5000 A. Measurements have shown that operators near the demagnetizing devices could be exposed to fields of about 10 mT for a significant part of the working day.[7]

Electrolysis and Other Industries

Large currents used in producing aluminum and other electrolytic processes produce static or pulsed direct current magnetic fields. Measurements indicate that occupational exposures in an aluminum manufacturing plant range from 10 mT to 50 mT. For other electrolytic processes, operator exposures range from 0.5 to 4 mT.[3]

Video Display Terminals and Other Devices

VDTs are an essential part of almost every modern office and concern of possible health effects of these devices is widespread. One researcher found that levels of an extremely low frequency (50 Hz to 60 Hz) magnetic field ranged from 0.76 A/m to 4.0 A/m (0.95 uT to 5 uT) close to the VDT and from 0.2 A/m to 0.35 A/m (0.25 uT to 0.44 uT) at 30 cm from the terminal. VDTs also emit magnetic fields in the very low frequency (VLF) range.[8]

Measurements of 60 Hz magnetic fields from electric blankets indicate exposure levels are about 0.3 uT or 0.4 uT. Exposure to 60 Hz magnetic fields from electrically heated waterbeds is about 1.5 uT.[9] Exposure to these fields can be significant because users are usually in close contact with the blanket or bed for long periods of time.

4. POTENTIAL HEALTH AND SAFETY HAZARDS FROM EXPOSURE TO STATIC MAGNETIC FIELDS

Studies show that static magnetic fields can cause specific effects.

- Blood flowing through the heart of a person in a static magnetic field produces a voltage, observed as a blip on an electrocardiogram. Experiments indicate that this voltage does not affect the heart's natural rhythm.[2]
- Exposure to static magnetic fields can cause an increase in blood pressure. Blood pressure rises about 1 percent in a field strength of about 2 T, 5 percent in a 5 T field and 10 percent in a 8 T field.[1]
- A 1982 study suggests that in the aluminum smelting industry, workers exposed to strong static magnetic fields from high DC currents used in electrolysis had an increased risk of leukemia. Two other studies on workers exposed to static magnetic fields did not detect an increased risk of cancer.[1]

- East European studies indicate that workers exposed to static magnetic fields experience irritability, fatigue and headaches. In the USSR, welders exposed to short pulses of static magnetic fields of 1000 to 100,000 A/m (1.25 mT to 125 mT) had nervous system disorders and an increased white blood cell count.[1]

- Isolated molecules and cells, especially sickled red blood cells, rotate in a static magnetic field. Experts believe that sickled red blood cells may rotate and impede blood flow in strong magnetic fields, for example above 50 mT.[10]

- Magnetic fields can affect the pineal gland, an important part of a person's biological "clock." The gland plays a role in regulating the day/night cycles of the body. Research suggests that magnetic fields can change the timekeeping of people when they are deprived of visual cues. Therefore, it has been suggested that it is unwise to allow workers who are exposed to magnetic fields above 50 mT, to work several consecutive shifts without a break.[2]

- Static magnetic fields can adversely affect cardiac pacemakers. These fields may cause a pacemaker to produce signals that could potentially compete with the heart's natural beat. Studies show that levels as low as 1.4 mT can affect pacemakers. It has been suggested that pacemaker wearers stay out of places where the field exceeds 0.5 mT.[2]

- Surgically implanted prosthetic devices, including aneurysm clips and various pins, could change position in a person who is in a strong magnetic field. This could be painful and potentially dangerous.[2]

- In very strong fields, hand tools or even compressed-gas cylinders could become dangerous flying objects and pose serious safety hazards.[2]

5. POTENTIAL HEALTH HAZARDS FROM EXPOSURE TO TIME-VARYING MAGNETIC FIELDS

Growing evidence suggests that living systems respond to time-varying magnetic fields. One of the earliest recorded responses to magnetic fields are magnetophosphenes, the visual sensation of flickering light. Magnetic fields between 10 and 100 Hz and field strengths greater than about 10 mT produce the sensation. This effect occurs only during magnetic field exposure and is harmless for a short exposure. Researchers are unsure of the consequences of long-term exposure to field strengths which produce magnetophosphenes.[1]

A recent study, involving six independent laboratories, examined the effect of weak 100 Hz pulsed magnetic fields on developing chick embryos. While differences exist between the findings of the individual laboratories, the project as a whole concluded that very low-level, very low-frequency pulsed magnetic fields contribute significantly to increase the rate of abnormalities in early embryonic chicks.[11] Since the mechanism of the effect on the chick embryos is presently unknown, it is not possible to conclude whether similar effects could be expected in people.

Some evidence suggests that the use of electric blankets or electrically heated waterbeds results in an increased risk of miscarriage.[9] Another recent study links VDT work with an increased risk of miscarriage.[12] There is no conclusive proof that magnetic fields from these devices are the cause.

Several studies report a higher rate of leukemia in people in electrical or electronic occupations who are likely exposed to 50 Hz or 60 Hz magnetic fields. One researcher noted that power station operators had a death rate from leukemia two and a half times the expected rate.[13] A recent review of studies of the health effects of working with electrical equipment concluded that electrical workers appear to be at increased risk of leukemia. However, the authors state that it was not possible to determine if the increase in leukemia is due to electromagnetic fields or to other factors to which electrical workers are exposed.[14]

Some studies of people living near high current powerlines show an increased rate of cancer. Other studies show no such association. Although the risk of developing cancer from exposure to power frequency fields is far from proven, experts believe that there is an urgent need for more research in this area.[13]

6. EXPOSURE STANDARDS AND GUIDELINES

Canada has no magnetic field exposure regulations other than guidelines for MRI operators. A guideline is a set of rules which people can follow voluntarily. A regulation or standard is a set of rules which the appropriate regulatory agency legally enforces.

Static Magnetic Fields

There are only a few guidelines for limiting occupational exposure to static magnetic fields. Table 1 outlines limits from the USSR, American Conference of Governmental Industrial Hygienists, US Department of Energy, and independent laboratories. Only the USSR has a national standard.

As well, there are guidelines for operator exposure limits to static magnetic fields from clinical magnetic resonance imagers (MRI). Table 2 lists British and Canadian guidelines.

Time-Varying Fields

Several organizations have proposed guidelines limiting exposure to time-varying magnetic fields. Table 3 summarizes these guidelines.

Table 1 - Summary of static magnetic field exposure guidelines[1]

Organization	Field Strength Limit	Exposure Time	Body Region
USSR	0.01 T	8 h	whole body
Stanford Linear Accelerator Center	0.02 T	extended (h)	whole body
	0.2 T	short (min)	whole body
	0.2 T	extended (h)	hands/arms
	2 T	short (min)	hands/arms
US Dept. of Energy	0.01 T	8 h	whole body
	0.1 T	1 h or less	whole body
	0.5 T	10 min or less	whole body
	0.1 T	8 h	hands/arms
	1 T	1 h or less	hands/arms
	2 T	10 min or less	hands/arms
CERN Accelerator Lab Geneva, Switzerland	0.2 T	minutes	whole body
	2 T	short (min)	hands/arms and feet
Lawrence Livermore National Laboratory (USA)	0.06 T	day	trunk
	0.6 T	day	extremities
	2 T	short (min)	whole body
American Conference of Governmental Industrial Hygienists	60 mT	day	whole body
	600 mT	day	extremities
National Radiological Protection Board (U.K.)	20 mT	2 h	whole body

h = hour min = minute T = tesla mT = millitesla

Table 2 - Summary of magnetic resonance imager exposure limits[1]

Organization	Field Strength Limit	Exposure Time	Body Region
National Radiological Protection Board (UK)	0.02 T	long periods	whole body
	0.2 T	long periods	arms/hands
	0.2 T	15 min	whole body
	2	15 min	arms/hands
Health and Welfare Canada	0.01 T	working day	whole body
	above 0.01 T	keep to minimum	-

Table 3 - Summary of time-varying magnetic field exposure limits[1]

Organization	Frequency (Hz)	Magnetic Field Limit (mT)	Exposure Duration
USSR*	50	7.5	1 h
		4.0	4 h
		1.8	8 h
ACGIH+	60	1.0	
NRPB**	less than 10	1.0	less than 2 h
	50	1.9	less than 2 h
	60	1.6	less than 2 h
	100	0.9	less than 2 h
	500	0.2	less than 2 h
IRPA	50/60	0.5	working day
whole body		5.0	less than 2 h
limbs		25.0	-

ACGIH = American Conference of Governmental Industrial Hygienists
NRPB = National Radiological Protection Board (U.K.)
IRPA = International Radiation Protection Association

Notes

* *The USSR standard issued in 1985 limits exposure to 50 Hz magnetic fields.*

\+ *The Physical Agents Committee of the ACGIH is considering a TLV (Threshold Limit Value) for low frequency magnetic fields in the range from 1 Hz to 20 kHz. It is based on the limit of 60 mT/f, where f is frequency in Hz. The TLV is intended as a guide for health professionals, not as a regulation.*[15]

** *The NRPB issued a draft proposal for limiting exposures to both electric and magnetic fields. The proposal establishes occupational magnetic field whole-body exposure limits for a period not exceeding 2 hours.*[16]

7. PROTECTION AND CONTROL

Various protective measures or administrative controls can reduce the hazards associated with magnetic field exposure. The preferred method of control depends upon the source and field levels. Techniques applicable to high energy technologies are not suitable for reducing exposure from, for example, video display terminals

In high energy technologies, one of the most fundamental control measures limits the amount of time people spend in areas of high magnetic fields. Since magnetic field strength decreases with distance from the source, another effective control measure is to separate people from the source.

Administrative controls include the use of warning signs and special access areas to limit exposure in areas of high magnetic fields (for example, above 50 mT). They must also restrict movement of some hand tools, for example screwdrivers, scissors and even compressed-gas cylinders, in and out of high magnetic field areas. Administrative controls should ensure that persons with cardiac pacemakers or other medical, electronic or electrical implants are not exposed to field levels above 1 mT.[10,17]

The use of shielding material to reduce magnetic field exposure is an expensive control measure. It requires careful engineering design, and special materials. Shielding may not be cost-effective for large installations when compared to the use of separation distance or other administrative controls.[1]

To reduce unnecessary exposure to weak magnetic fields, people may wish to take a prudent approach. For example, people can reduce their exposure to 60 Hz magnetic fields by voluntarily discontinuing the use of an electric blanket or electrically heated waterbed.[18] They may also wish to reduce magnetic field exposure from a VDT by changing to a liquid crystal display (LCD) or by increasing their distance from the VDT.[19]

APPENDIX A

Table - Measured magnetic field exposure levels of various electrical utility occupations[20]

Occupation	Magnetic Field (uT)	(mG)
Distribution Lineman	1.45	14.5
Transmission Lineman	1.31	13.1
Apparatus Electrician	3.44	34.4
Splicer	2.08	20.8
Apparatus Mechanics	1.18	11.8
Generating Station Assistant Operator	1.14	11.4

uT = microtesla
mG = milligauss

APPENDIX B

Table - Measured magnetic field strength at body of arc welder[21]

Location of Measurement	Mean (A/m)	Mean (uT)	Minimum (A/m)	Minimum (uT)	Maximum (A/m)	Maximum (uT)
Head	53	66	0.3	0.4	160	200
Chest	72	90	3.0	3.8	210	263
Waist	140	175	0.4	0.5	350	438
Gonads	138	173	2.0	2.5	500	625
Hand	133	166	3.0	3.8	800	1000
Leg	115	144	4.0	5.0	300	375

A/m = amperes per meter
uT = microtesla

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